Overview of Position Accuracy Studies

For Use by ASSAP WG

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Outline

1. Position Error Results from:
   - 1090ES LDPU - March 2005 Flight Tests over Louisville, KY
   - UAT GDL-90 - Cumulative results from various flight tests, including Anchorage 11/2004, Juneau 10/2004, Atlantic City 8/2004, and 10/2005.

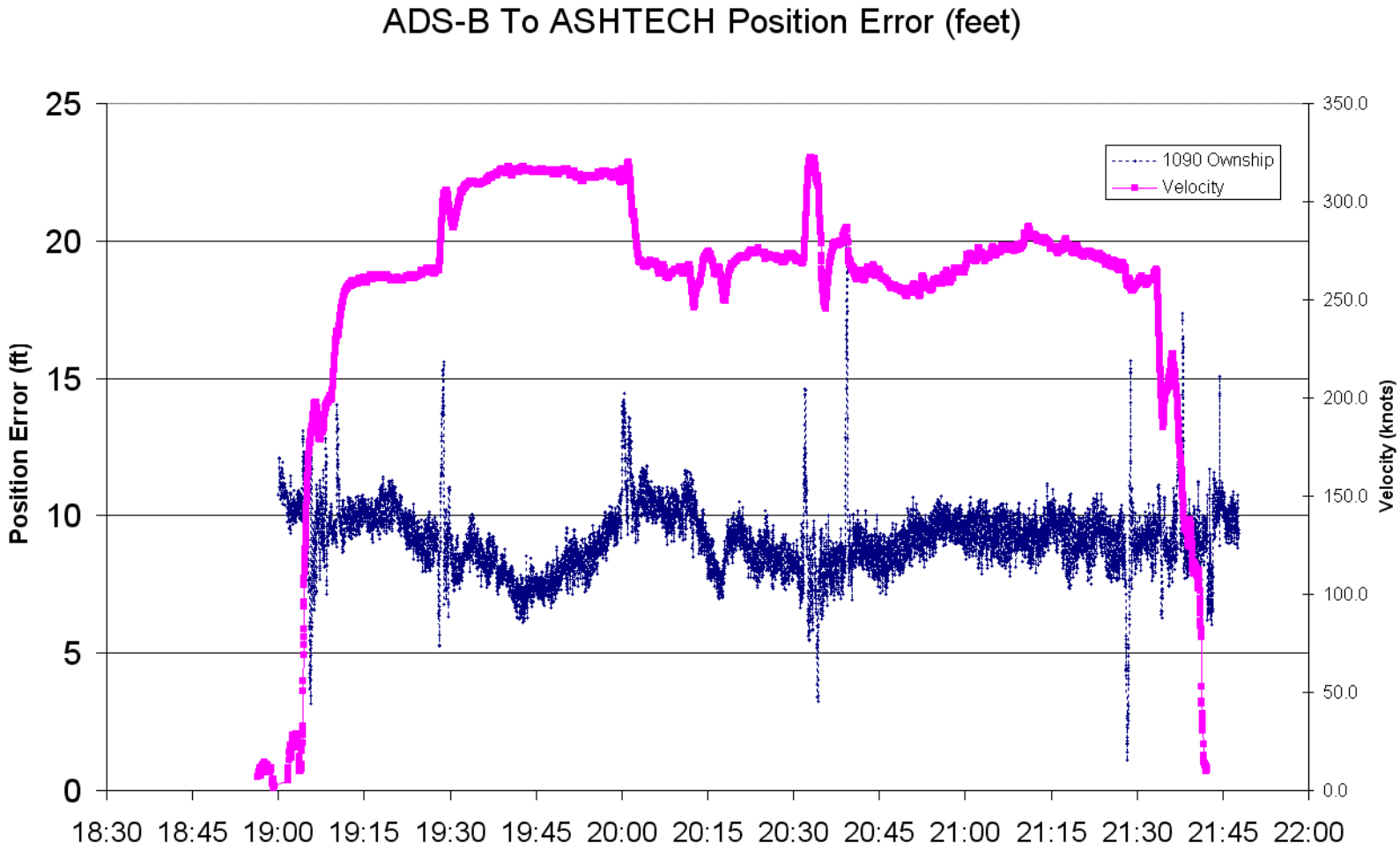
2. Studies of typical equipage:
   - 1090ES in Louisville
   - UAT in the East Coast

This brief is meant to be an overview of the available ADS-B data. It is not meant to be a comprehensive assessment of all ADS-B equipages in all environments.

1090ES LDPU Overview

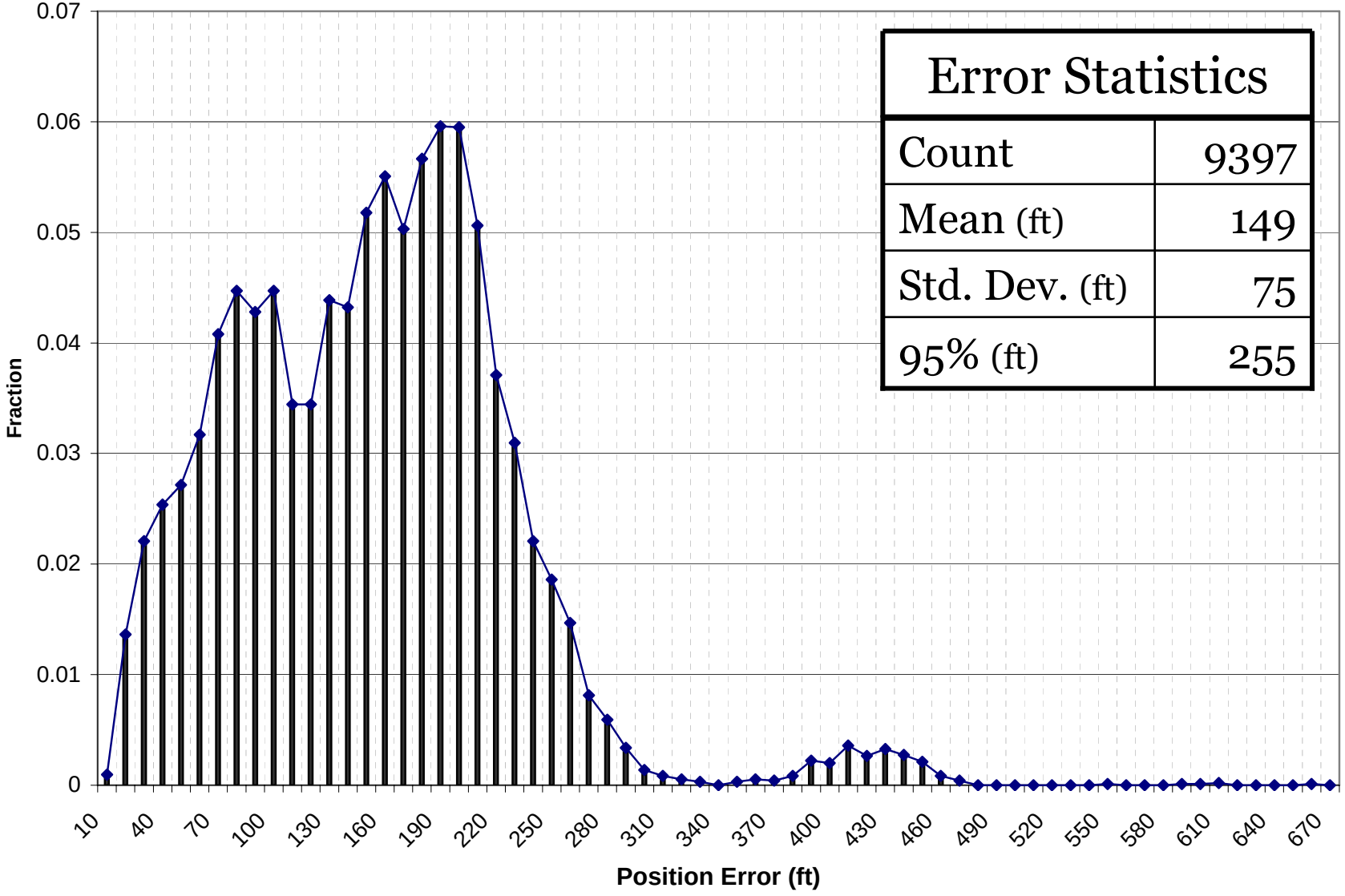
- Flight Tests were conducted at Louisville Standiford Airport
  - March 9, 2005
- N39 Convair 580 Aircraft
  - 1090ES avionics
- Data sources
  - Ashtech data recorders (500 ms updates)
  - Avionics Ownship
    - Extracted from LDPU Flash Drive on LDPU Avionics
    - Data set includes either GPS or FMC (Flight management computer) position data along with altitude encoder data archived as they are received onboard by the LDPU.
  - Avionics 1090 Rx Ownship
    - Extracted from 1090Rx Flash Drive on LDPU Avionics (separate drive from above)
    - Message generation logic used to combine position and velocity messages
    - TOA is calculated (by JHU) as per 1090 MOPS (non-precision = t_Rx – 0.1 sec)
    - These messages are archived after the Ownship positions have traversed the Transmit and Receive subsystems.
- Ashtech times were interpolated to ADS-B TOA
- Great circle distances between ADS-B and Ashtech lat/long positions were calculated and plotted versus time

ADS-B Distance Error vs. Time



Reported integrity and accuracy (100% NUCp = 7)

1090 Rx Ownship Distance Error Distribution

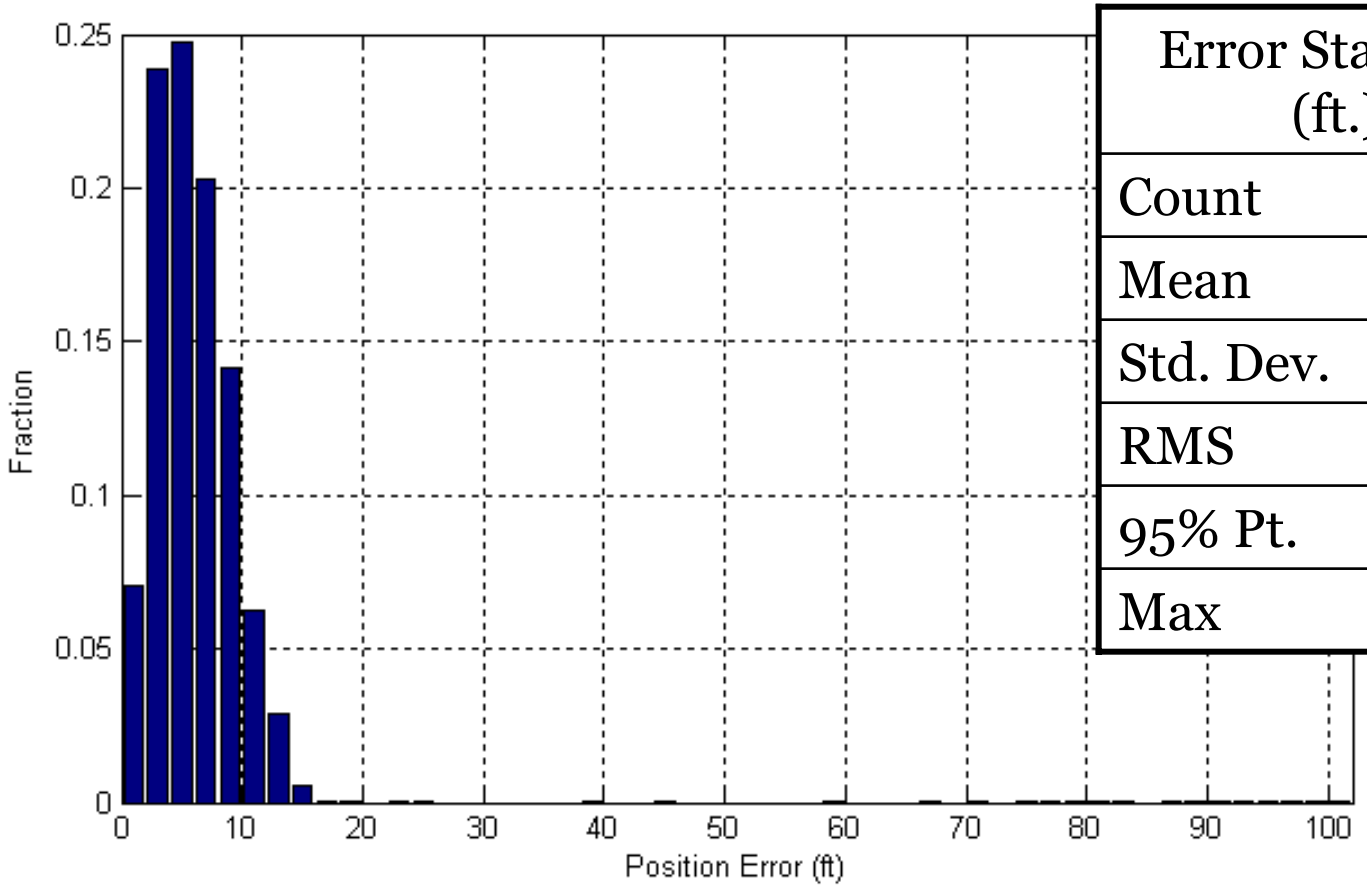


Error Statistics	
Count	9397
Mean (ft)	149
Std. Dev. (ft)	75
95% (ft)	255

UAT Position Accuracy Overview

- Test aircraft:
  - FAA N39 and N49,
  - University of Alaska (UAA) (Juneau only)
- Data sources
  - CARTS EX data class
  - JHU/APL CRABS archives
  - MEARTS EX data class
- Ashtech times were interpolated to ADS-B TOA
- Great circle distances between ADS-B and Ashtech lat/long positions were calculated and plotted versus time

UAT ADS-B Sensor Reported Position Accuracy @ TOA - Error Distribution for All Flight Tests



Error Statistics (ft.)	
Count	42513
Mean	5.9
Std. Dev.	4.7
RMS	7.6
95% Pt.	11.4
Max	471

*Two values are not shown above: 471 ft. and 415 ft. Both occurred at the same time on different aircraft, and reported NIC =9 and NACp=9.

*NACp<4 and NIC<4 were removed from statistics.

UAT NIC and NACp Values for all Flight Tests

NIC Table (count=43756)		
Val	Count	Percentage
0	1232	2.82 %
1	0	0 %
2	0	0 %
3	0	0 %
4	1	<0.01 %
5	1	<0.01 %
6	10	0.02 %
7	23	0.05 %
8	6802	15.55 %
9	11368	25.98 %
10	24319	55.58 %

NACp Table (count=43756)		
Val	Count	Percentage
0	982	2.24 %
1	0	0 %
2	0	0 %
3	0	0 %
4	0	0 %
5	0	0 %
6	0	0 %
7	6	0.01 %
8	840	1.92 %
9	41928	95.82 %
10	0	0 %

*Airborne reports (speed >35 knots) only transmitted NIC>=8 and NACp>=8 (except for 6 NACp=0 reports).

Selected Slides from an older brief:

Some Issues Observed in Operational ADS-B Datalinks

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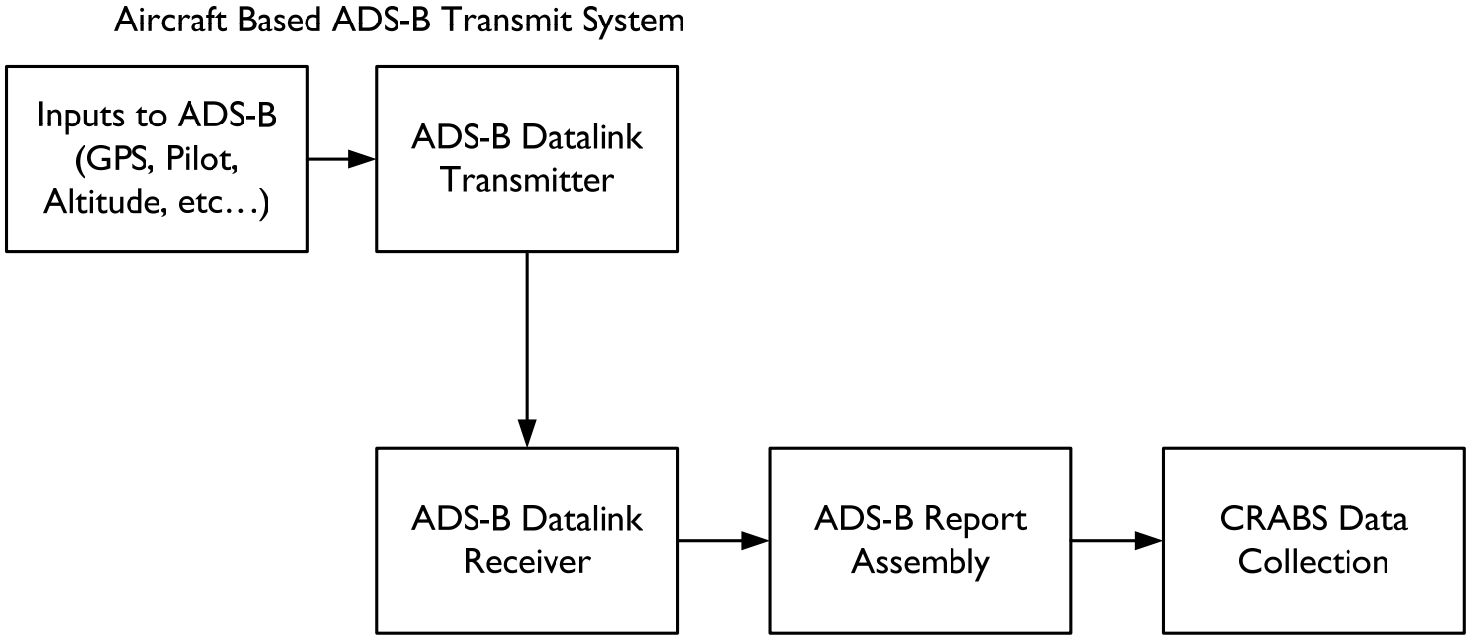
Notes on Analysis of Current Datalink Implementations

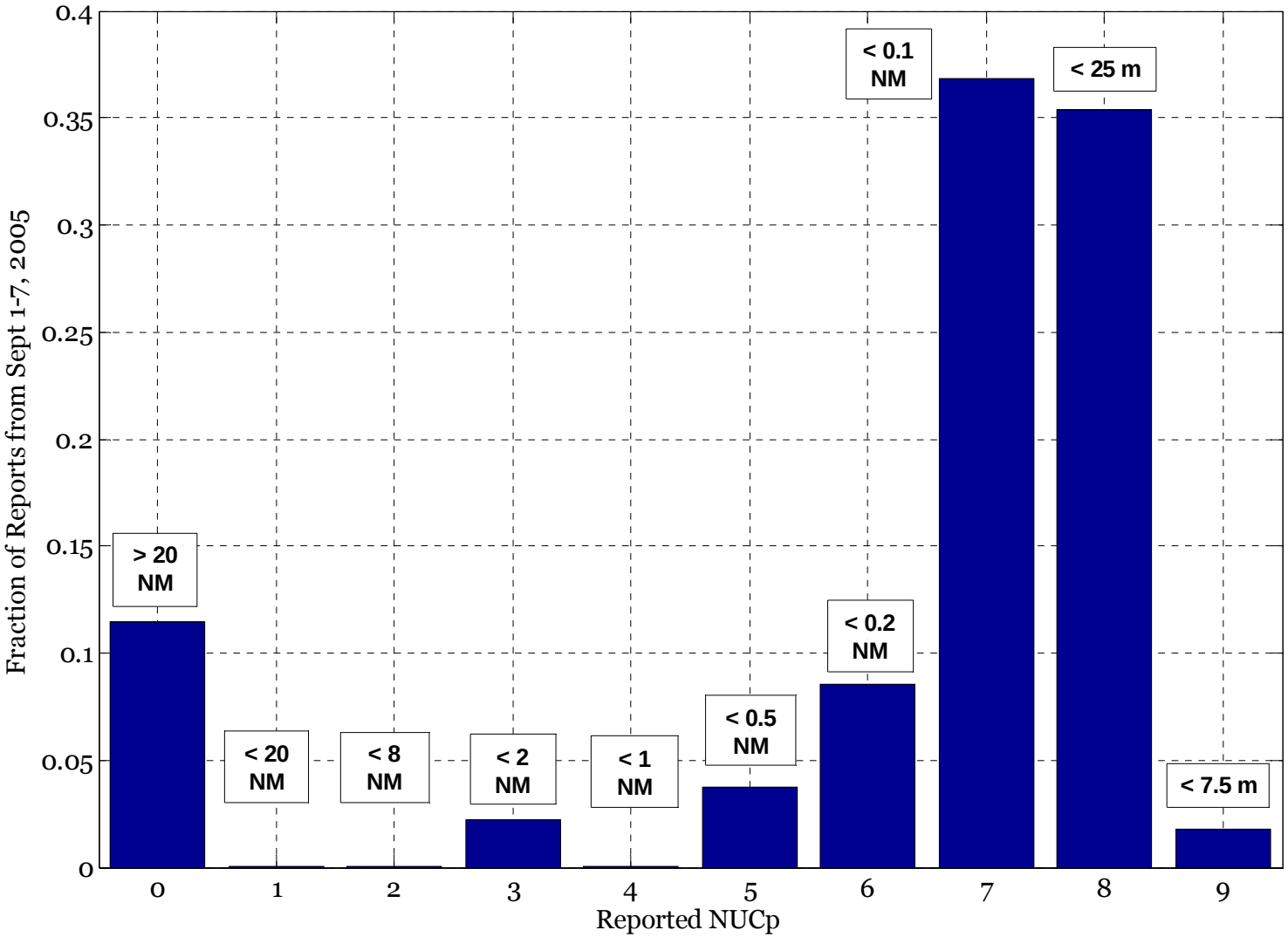
- Remainder of briefing provides examples of incorrect / insufficient / anomalous data reported from ground receivers
- Arbitrarily picked the week of September 1-7, 2005 to examine:
  - 1090ES data for aircraft near Louisville
  - UAT data for aircraft on East Coast of CONUS
- Current 1090ES datalink installations (for the most part) predate TSO C-166
- UAT installations are compliant with TSO C-154

The Problem of Isolating Faults

- ADS-B is a distributed system – faults can occur in and in between each piece of equipment, or by human inaction
- The data collected here is Reports issued from a ground receiver – no definitive answer on what is "wrong" when anomalies occur

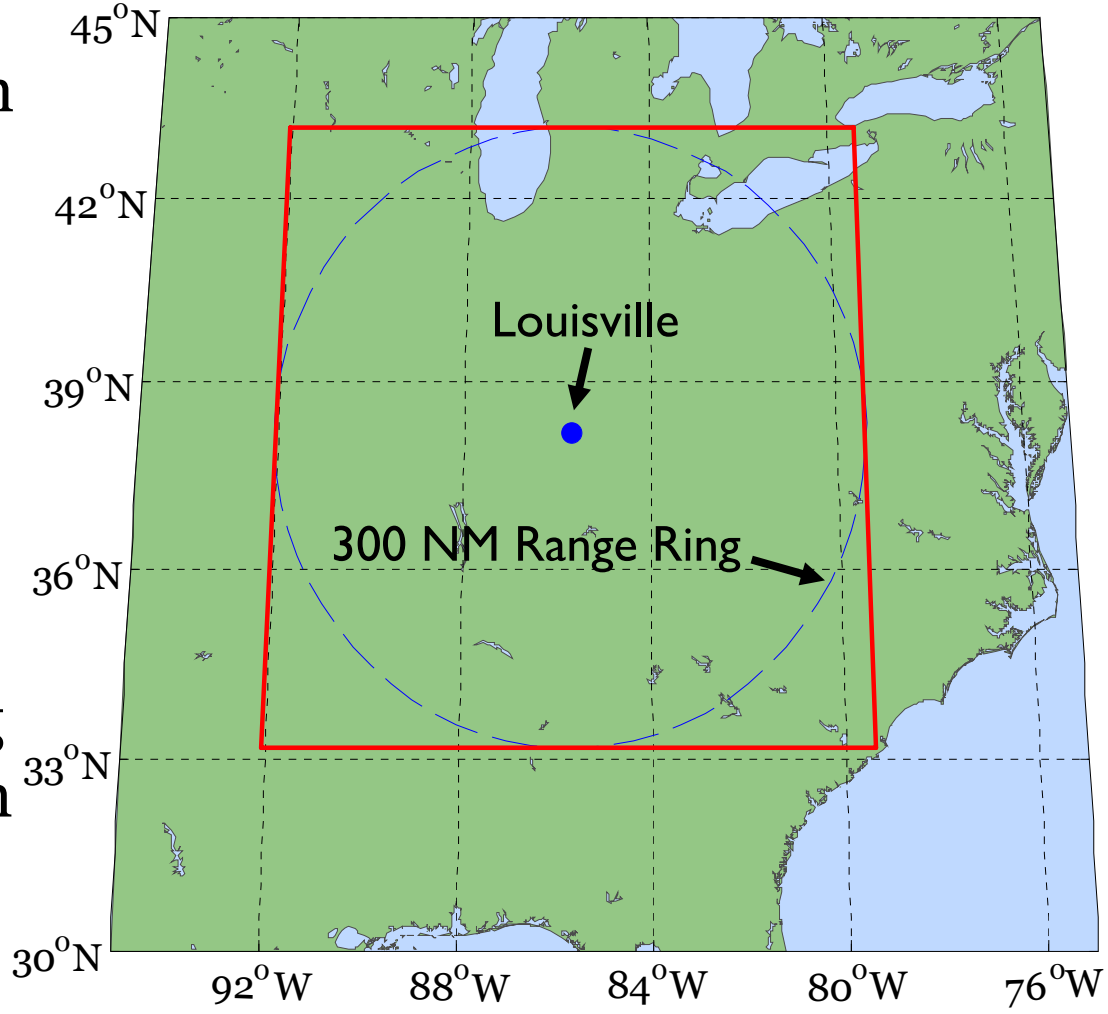


Reported NUC_P Values (and inferred R_C) for Louisville from 9/1 through 9/7



Position Anomalies in Current 1090ES Data

- Quick sanity check on reported position in received 1090ES messages from Louisville
- Applied a filter that looked at reported positions outside of a simple box inscribing a 300 NM range from SDF



Position Anomalies in Current 1090ES Data (2)

Looking at all received data from 0:00 Zulu on September 1, 2005 through 23:59 Zulu on September 7, 2005:

- 399 Unique ICAO Addresses
- 81 Unique ICAO Addresses that had at least one position reported "outside the box" (about 20%)
  - Of these 81aircraft, on average, 65% of the reports out of the GBT from these aircraft had a position "outside the box"
- Approximately 3 million ADS-B reports issued from 1090ES GBT in Louisville
- Approx. 115,000 ADS-B reports that reported position "outside the box" (about 4%)

Position Anomalies in "Worst Offender"

- One aircraft had "Nothing but Bad" position data. Taking a closer look at this aircraft:
  - 709 reports issued from GBT on September 1, 2005
  - Longitude was set to -90 degrees for all reports
  - Latitude, altitude, & velocity were set to 0 degrees for all reports
  - NUCp was set to 7 for all reports
    - Indicates a < 0.1 NM integrity alerting error at 10^{-5} per flight hour & 95% Accuracy < 0.05 NM
  - No call sign reported

Other Anomalous Behavior in ADS-B Reports from SDF during Sept. 1-7, 2005

Recall that there were 399 unique aircraft observed during this week

- Pressure Altitude
  - 57 unique aircraft reported altitudes ≤ -1000 ft. or altitudes ≥ 45,000 ft.
- Identification
  - 16 unique aircraft reported no Call Sign (~70,000 reports)
    - 163 aircraft reported 100% consistent call signs
  - 214 Reports from obviously invalid ICAO Address
    - How do you verify a bad ICAO?
    - Related to another issue - 217 Reports failed CRC test due to bit shifting – unclear what is the source of error
- Velocity
  - 372 aircraft were reported to have Zero (0) Velocity when greater than 1000 ft. pressure altitude for at least one report
    - 15% of Reports issued for this week (462,000 reports)
  - 40 aircraft never reported velocity (out of an average 1700 reports)
  - 12 aircraft showed a speed > 200 knots when 1500 ft. or lower – mostly due to altitude getting zeroed out

UAT Data on East Coast Deployment

- ADS-B data from the East Coast network archive were analyzed to identify anomalous UAT performance
  - September 1 through September 7, 2005
- 6,756,675 UAT Reports were processed
- 112 unique ICAO 24-bit Addresses were observed
  - 110 appeared to be valid aircraft reports
  - "0" Address commonly observed at avionics start-up – Likely a GBT Issue

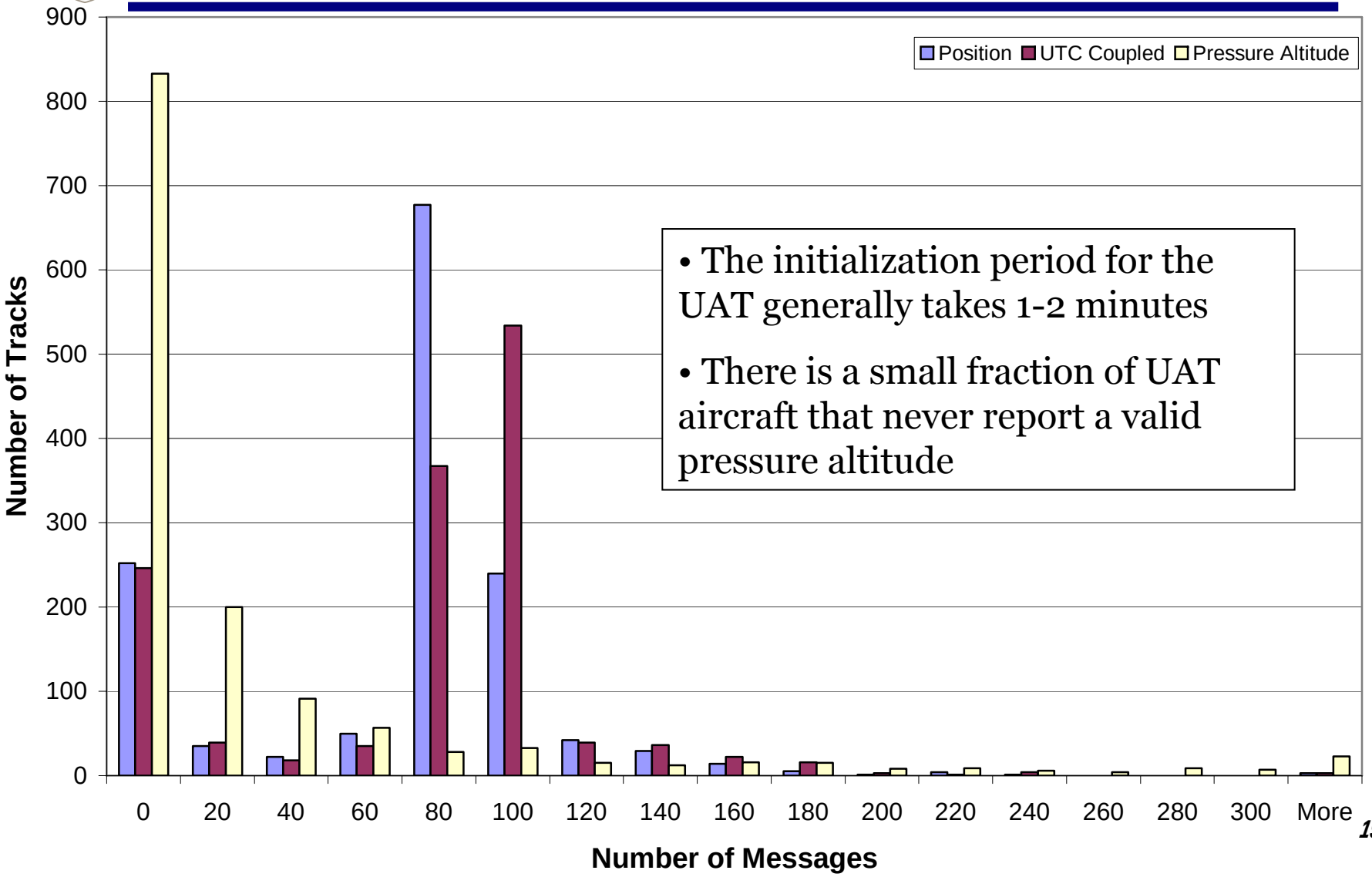
Observed Broadcast UAT Data Anomalies

- Pressure Altitude
  - ~4% (241,828) of all UAT Reports did not contain pressure altitude
  - Two aircraft never reported a pressure altitude
  - Many other aircraft had intermittent pressure altitudes
  - Others took a long time before first report of Pressure Altitude
    - Need pilot to activate the pressure encoder?

- Invalid Air Ground Determination
  - Five aircraft appear to always report an airborne state whether on the surface or airborne
  - This conservative approach is not in conflict with MOPS

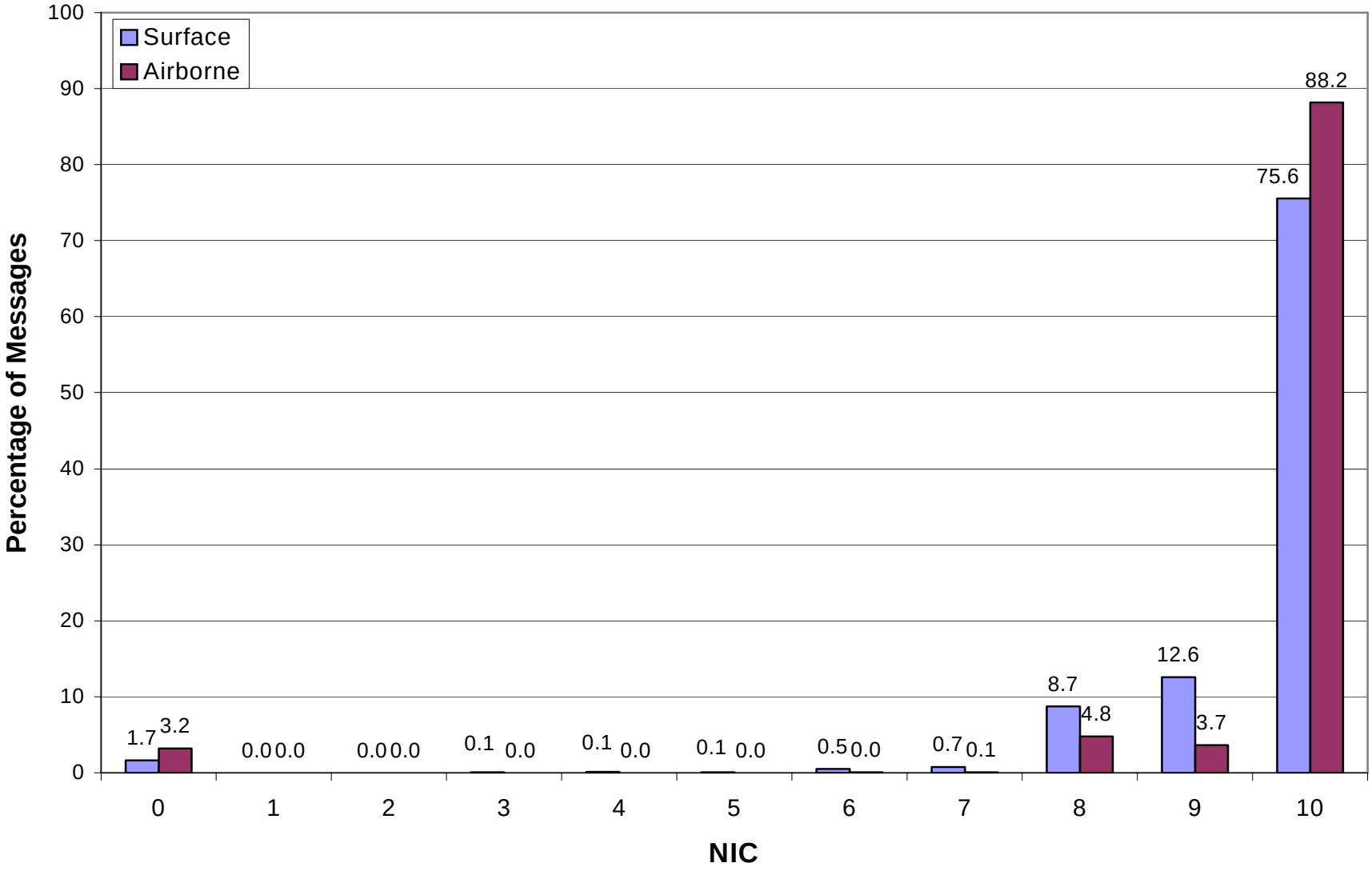
- Rapid Transitions in Integrity (NIC → 0)

Initialization of ADS-B Data Quantities after 1st Message Received at GBT (9/1-9/7)



- The initialization period for the UAT generally takes 1-2 minutes
- There is a small fraction of UAT aircraft that never report a valid pressure altitude

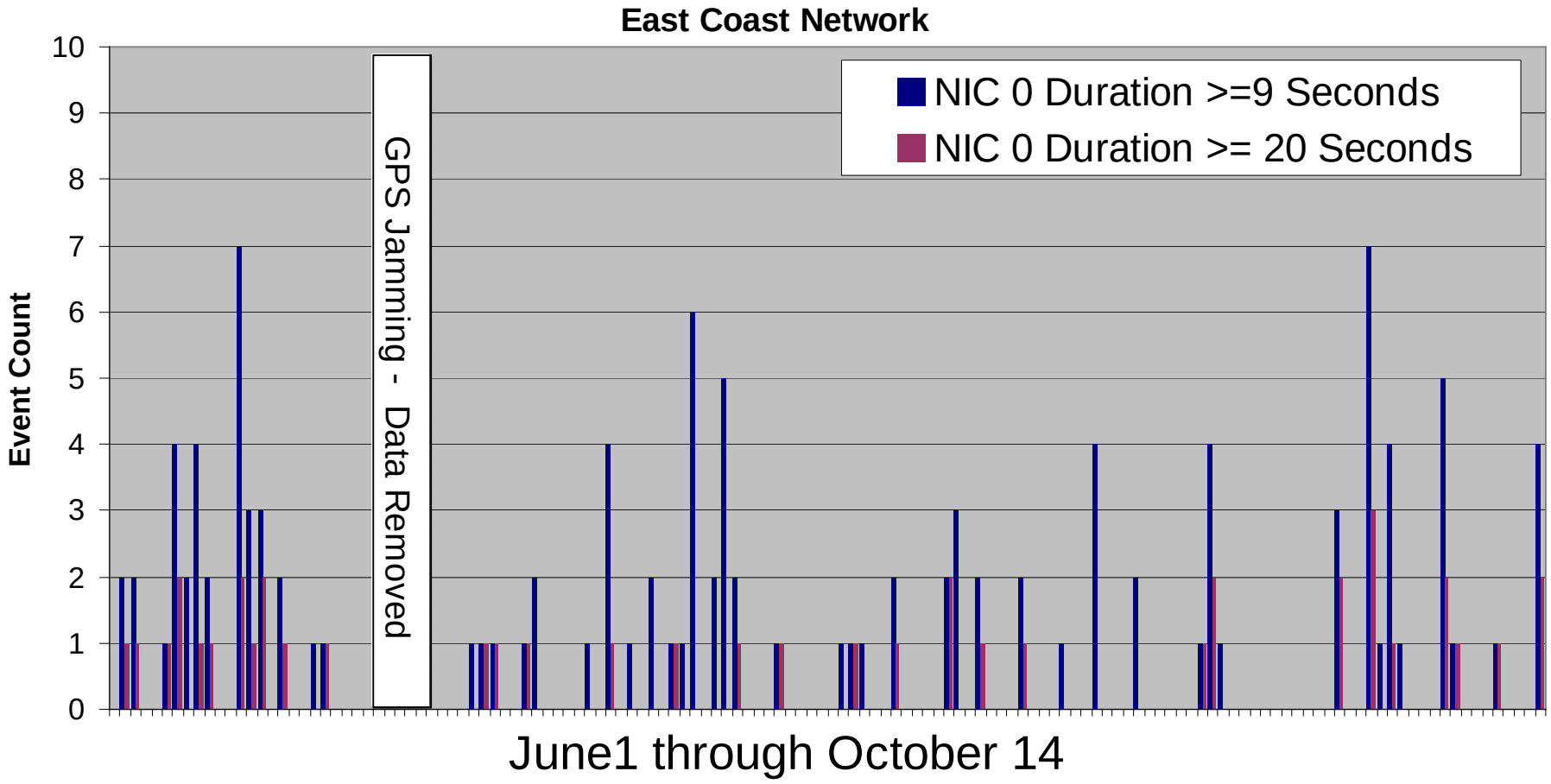
Aircraft NIC Values (9/1-9/7)



UAT Integrity Issues

- Integrity is intended to be a slowly varying parameter
  - NIC will be applied as a criterion for enabling most applications
- UAT reports with zero NIC values are observed during flight, indicating unknown position integrity
- JHU/APL has analyzed the frequency and duration of the zero NIC events for the East Coast Network

Daily Frequency of NIC 0



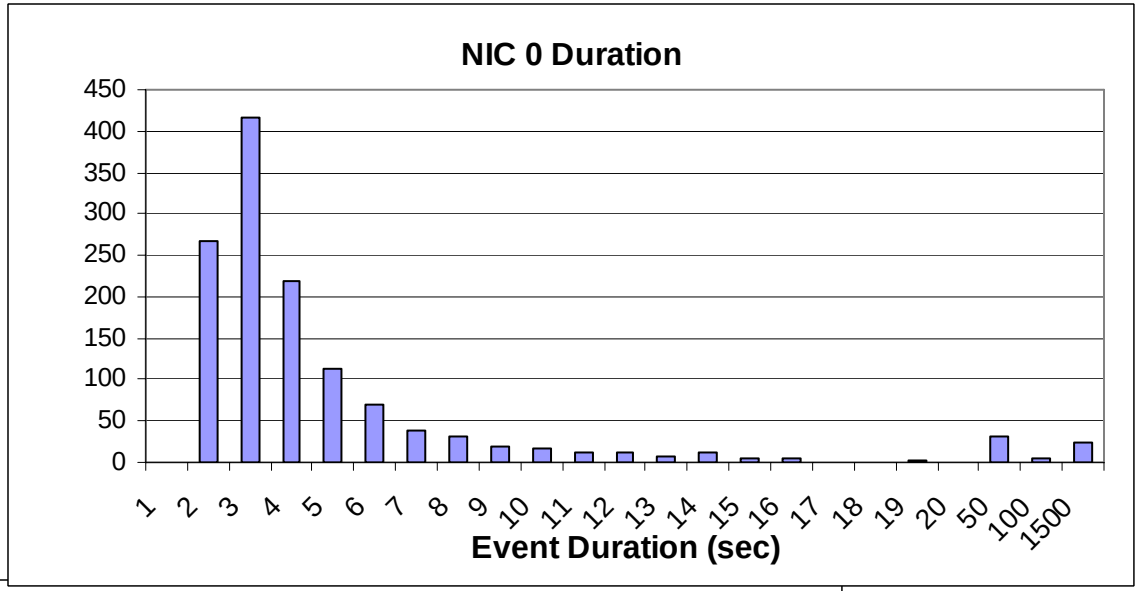
Statistics for NIC 0 Events

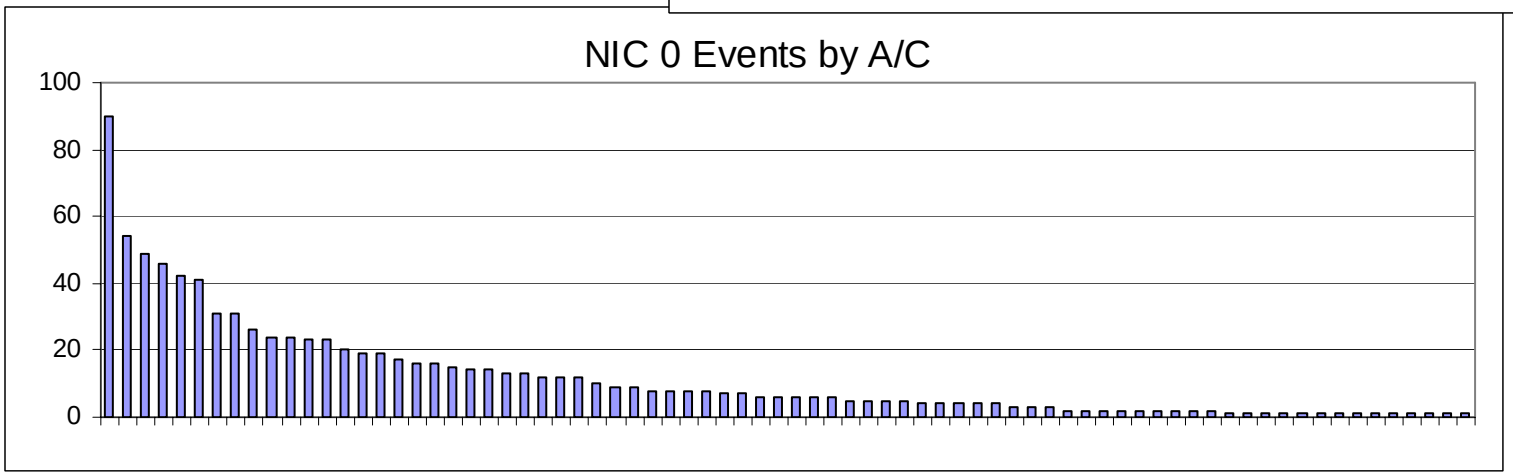
- 136 days in the data from last slide
- 134 unique aircraft observed
- Number of NIC 0 events observed:
  - Excluding helicopters: 120 in 23417 flight hours
  - Including helicopters: 163 in 25266 flight hours
- Events per flight hour
  - Excluding helicopters: 3.3×10^{-5}
  - Including helicopters: 4.3×10^{-5}
- 0.88 Events per day (excluding helicopters)

More Characterization

- Duration Histogram
  - Peaks at 3 seconds
  - 90% below 10 seconds
- Events by A/C Histogram
  - 29% of A/C account for 90% of events

*Includes only airborne A/C





What is the Cause ?

The problem has been looked at from various perspectives to identify trends:

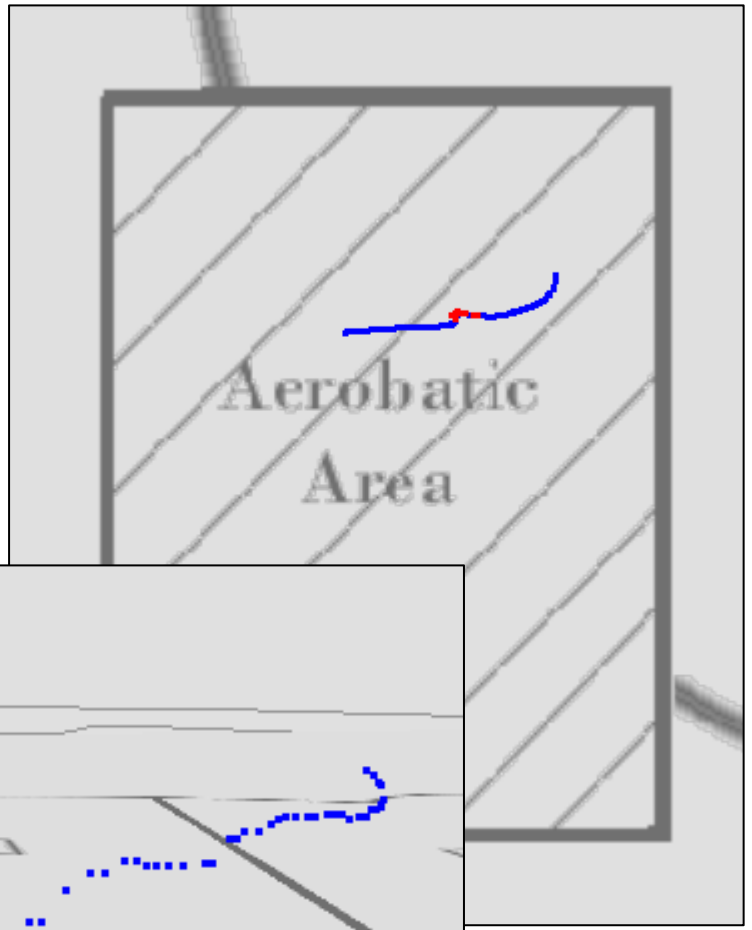
- Frequency within fleets / types of aircraft
  - ERAU Prescott and Daytona Beach, East Coast, Helicopters
- State Vector Trends (before and after event)
  - ΔHdg, ΔVel, ΔAlt
- Time of Day (events per hour)
- Events per flight hour

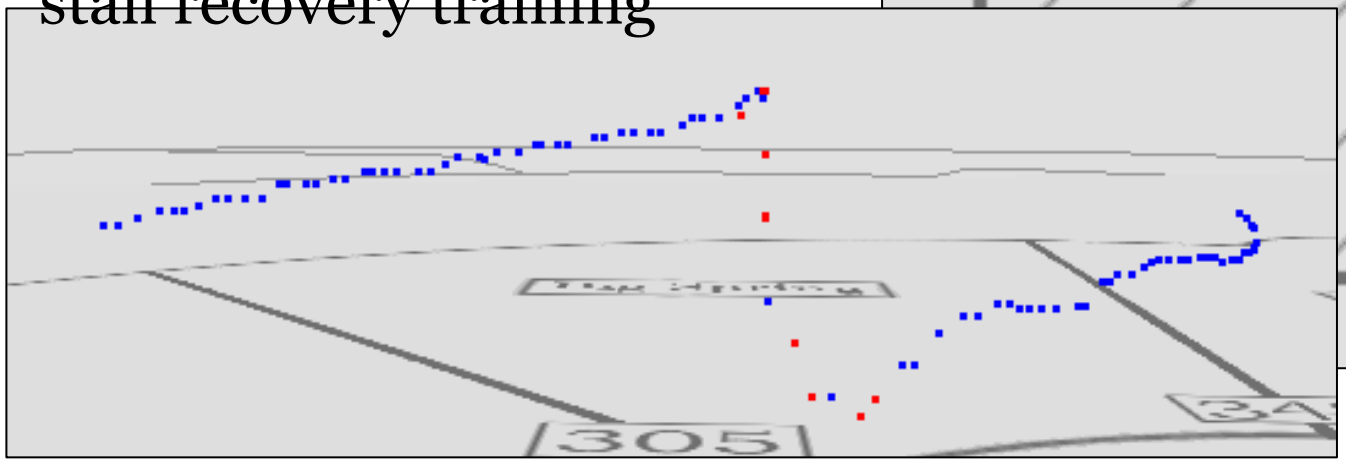
Data surrounding the events were plotted and organized into a web site to distribute within the analysis community.

- The track plots suggest that there may be a correlation with high rate maneuvers
- Currently investigating the frequency of high rate maneuvers resulting in NIC 0 events

Rapid Descents

- ERAU Prescott has many NIC 0 transitions that appear to be a result of rapid descent aerobatic maneuvers
- Aircraft may experience similar orientations during stall recovery training





Steep Turns

- NIC 0 transitions are frequently observed to occur during turning flight
  - 10–20 degree per second turns
- High bank angles may shield the GPS antenna from satellite view
  - ERU practices turns involving up to 55° bank angles